Table I-8. Inventory (kilograms)[a] of chemical materials placed in the Proposed Action repository.

	Inventory				
Element	Not part of engineered barrier system	Engineered barrier system components exposed before waste package failure	Internal to waste package including inner sleeve	High-level radioactive waste[b]	Totals
Aluminum	0	0	2,452,400	0	2,452,400
Barium	0	0	50,000	74,000[c]	124,000
Boron	0	0	197,400	0	197,400
Cadmium	0	0	3,400	43,000	46,400
Carbon	318,738	547	5,000	0	324,285
Chromium	0	23,735,000	26,414,000	0	50,149,000
Cobalt	0	0	27,000	0	27,000
Copper	243,800	0	3,000	0	246,800
Iron	111,916,880	1,190,000	161,695,000	0	274,801,880
Lead	0	0	0	2,000	2,000
Magnesium	0	0	12,000	0	12,000
Manganese	1,189,576	575,880	3,732,100	0	5,497,556
Mercury	0	0	0	200	200
Molybdenum	0	17,307,000	3,839,100	0	21,146,100
Nickel	0	60,797,000	18,659,100	0	79,456,100
Phosphorus	39,842	820	91,200	0	131,862
Selenium	0	0	0	300	300
Silicon	330,122	18,226	1,680,500	0	2,028,848
Sulfur	39,842	547	68,200	0	108,589
Titanium	0	4,148,000	2,000	0	4,150,000
Uranium	0	0	70,000,000	0	70,000,000
Vanadium	0	377,600	0	0	377,600
Zinc	0	0	3,000	0	3,000

a. To convert kilograms to pounds, multiply by 2.2046

b. The high-level radioactive waste form to be placed in the potential repository would not exhibit the Characteristic of Toxicity as measured by the Toxicity Characteristic Leaching Procedure (40 CFR 261.24).

c. Includes barium grown in from decay of all of the cesium.

to plutonium, no chemical toxicity benchmarks have been developed for this element. Therefore, lacking data to analyze chemical toxicity, plutonium was not analyzed for the chemical screening.

I.3.3 INVENTORY FOR ATMOSPHERIC RADIOACTIVE MATERIALS

The only radionuclide that would have a relatively large inventory and a potential for gas transport would be carbon-14. Iodine-129 can exist in a gas phase, but it is highly soluble and therefore likely to dissolve in groundwater rather than migrate as a gas. Radon-222 is a gas, but would decay to a solid isotope before escaping from the repository region (see Section I.7.3). After carbon-14 escaped from the waste package, it could flow through the rock in the form of carbon dioxide. About 2 percent of the carbon-14 in commercial spent nuclear fuel occurs in a gas phase in the space (or *gap*) between the fuel and the cladding around the fuel (DIRS 103446-Oversby 1987, p. 92). The gas-phase inventory consists of 0.122 curie of carbon-14 per commercial spent nuclear fuel waste package. Table I-9 lists the carbon-14 inventory for commercial spent nuclear fuel under the Proposed Action and Inventory Modules 1 and 2.

I.4 Extension of TSPA Methods and Models for EIS Analysis of Long-Term Performance

The TSPA model nominal scenario is equivalent to the Proposed Action inventory for an individual at the RMEI location [approximately 18 kilometers (11 miles) downgradient from the proposed repository]. Details on the adaptations, extensions, and modifications to the software and models used for the TSPA

Table I-9. Carbon-14 gaseous inventory from commercial spent nuclear fuel (curies).[a]

Modeled inventory	Quantity[b]
Proposed Action	959
Module 1	1,434
Module 2	1,434

a. Impacts of carbon-14 in solid form are addressed as waterborne radioactive material impacts.

b. Based on 0.122 curie of carbon-14 per commercial spent nuclear fuel waste package, based on 2 percent of the carbon-14 in commercial spent nuclear fuel existing as a gas in the gap between the fuel and the cladding around the fuel (DIRS 103446-Oversby 1987, p. 92).

model necessary to analyze impacts under Inventory Modules 1 and 2 and at additional individual locations 30 and 60 kilometers (19 and 37 miles) downgradient from the repository are presented in this section.

I.4.1 METHODOLOGY

The calculations presented in this EIS were performed using the numerical code GoldSim, Version 7.17.200 (DIRS 155182-BSC 2001, all). The GoldSim calculations were performed for the conceptual/ process modeling of the proposed Yucca Mountain Repository described in the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, all) and expanded upon in the *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-BSC 2001, all; DIRS 154659-BSC 2001, all).

The performance assessment calculations for both the TSPA–Site Recommendation, the Supplemental Science and Performance Analyses, and the analysis of long-term performance calculations described in this EIS were performed within a probabilistic framework combining the most likely ranges of behavior for the various component models, processes, and corresponding parameters included in the overall conceptual/process model describing the performance of the repository.

The GoldSim software integrated the submodels using a Monte-Carlo simulation-based methodology to create multiple random combinations of the uncertain variables, and computed the probabilistic performance of the entire waste-disposal system in terms of annual individual dose. The GoldSim software calculated radionuclide release and radiological dose (the annual committed effective dose equivalent as defined in 40 CFR 197.2 from individual radionuclides and the total annual dose due to all radionuclides released from the repository from failed waste packages). In this EIS, the annual committed effective dose equivalent is referred to as the annual individual dose. GoldSim calculated the total annual dose for 300 realizations of the model configuration for the nominal scenario, and 5,000 realizations for the igneous activity scenario, using randomly selected values of distributed parameters for each realization. The calculation results are available in two main forms: (1) probability distributions for peak dose to an individual, and (2) time histories of annual dose to an individual.

The recently promulgated Environmental Protection Agency Final Rule 40 CFR Part 197 stipulates that the performance assessment of the proposed Yucca Mountain Repository include an estimate of dose to the reasonably maximally exposed individual. The Rule further states that this assessment provide, for 10,000 years, the reasonably maximally exposed individual annual committed effective dose equivalent (40 CFR 197.20 and 197.25). For the purposes of this EIS, the analysis of long-term performance must calculate the peak dose that would occur within the period of geologic stability (40 CFR 197.35). The peak dose is projected to occur within 1,000,000 years.

The methodology used for the calculations presented in this EIS draws upon the extensive analyses carried out in support of the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, all) and in the *FY01 Supplemental Science and Performance Analyses,* Volumes 1 and 2 (DIRS 155950-BSC 2001, all, and DIRS 154659-BSC 2001, all). Only those model components and related parameters that were modified to account for the scenarios considered in addition to those used in the TSPA–Site Recommendation or the *FY01 Supplemental Science and Performance Analyses* are described in this EIS. In addition, the model configuration used for the calculations presented in this EIS was modified to conform to the recently promulgated U.S. Environmental Protection Agency Final Rule. The Final Rule provides the criteria to be used in determining the RMEI location [40 CFR 197.21(a)], the other criteria of the RMEI (that were applied in the calculation of biosphere dose-conversion factors), and the groundwater protection standard, including the representative volume to be used for the calculation of gross alpha activity, total radium activity, and whole-body dose (40 CFR 197.30, Table 1). These modifications are described in Section I.4.4.

This EIS considers inventories in addition to those described in the TSPA–Site Recommendation and the *Supplemental Science Performance Analyses* for the 70,000 MTHM inventory. The calculations in this EIS include the Proposed Action (70,000 MTHM inventory) under both the higher-temperature repository operating mode and lower-temperature operating mode, and the Module 1 and 2 inventories under the higher-temperature operating mode, for the following scenarios:

- The nominal scenario that considers performance of the repository under undisturbed conditions, but including seismic activity.

- The human intrusion scenario (DIRS 153246-CRWMS M&O 2000, Section 4.4, pp. 4-25 to 4-32), that considers an "intruder" drilling a land-surface borehole using a drilling apparatus (under the common techniques and practices currently employed in exploratory drilling for groundwater in the region around Yucca Mountain), drilling directly through an intact or degraded waste package, and subsequently into the uppermost aquifer underlying Yucca Mountain. The intrusion then causes the subsequent compromise and release of contaminated material in the waste package. The human-intrusion scenario was simulated for a 1-million year performance period with the intrusion at 30,000 years after repository closure.

- The igneous activity scenario contains two separate possible events: a volcanic eruption that includes exposure as a result of atmospheric transport and deposition on the ground, and an igneous intrusion groundwater transport event (DIRS 155950-BSC 2001, Section 14.2.1, p. 14-5). In the volcanic eruption event (DIRS 153246-CRWMS M&O 2000, Section 3.10, pp. 3-187 to 3-216), a dike (or dikes) would intersect the repository and compromise all waste packages in the conduit. Then, an eruptive conduit of an associated volcano would intersect waste packages in its path. Waste packages in the path of the conduit would be sufficiently damaged that they provide no further protection, and the waste in the packages would be entrained in the eruption and subject to atmospheric transport. In the igneous intrusion groundwater transport event, the analysis calculated releases caused by a dike (or dikes) intersecting emplacement drifts, causing varying degrees of waste-package damage.

I.4.2 ASSUMPTIONS

This section identifies assumptions that are essential for this calculation. The assumptions listed here contribute to the generation of results reported in Sections I.5 and I.6 of this appendix.

1. The Proposed Action (70,000-MTHM) model configuration for the calculations in this EIS consists of the *FY01 Supplemental Science and Performance Analyses* model (DIRS 155950-BSC 2001, all), which differs from the TSPA–Site Recommendation model (DIRS 153246-CRWMS M&O 2000, all).

The model used for the calculations in Sections I.5 below includes the modifications from the Supplemental Science and Performance Analyses and TSPA–Site Recommendation models as described below in Section I.4.4. Other assumptions incorporated into the Supplemental Science and Performance Analyses model are documented in the *FY01 Supplemental Science and Performance Analyses* Volume 2 (DIRS 154659-BSC 2001, Section 2, all). The key differences between the Supplemental Science and Performance Analyses and the model configuration used in the calculations presented in this EIS are described in Section I.4.4.

2. The radionuclide inventories used in the calculations in Section I.5 are those developed in the *Inventory Abstraction* Analysis Model Report (DIRS 154841-BSC 2001, Table 36, p. 38). The per-waste-package inventories for commercial spent nuclear fuel and codisposal waste packages are the same as those used in the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, Section 3.5.1, pp. 3-94 to 3-100), but the DOE-owned spent nuclear fuel inventory does not include naval spent nuclear fuel. The naval spent nuclear fuel is conservatively represented by commercial spent nuclear fuel (DIRS 152059-BSC 2001, all, and DIRS 153849-DOE 2001, Section 4.2.6.3.9, p. 4-257). The per-waste-package inventories used for the Greater-Than-Class-C calculations use the Greater-Than-Class-C inventory presented in Attachment VI of the *EIS Performance–Assessment Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain* (DIRS 155393-CRWMS M&O 2000, p. VI-5) divided according to the number of packages indicated in DIRS 155393-CRWMS M&O (2000, Attachment VI).

I.4.3 USE OF COMPUTER SOFTWARE AND MODELS

The calculations described in this EIS were performed using the numerical code GoldSim, Version 7.17.200 (DIRS 155182-BSC 2001, all). GoldSim was developed by Golder Associates as an update to the baseline software RIP v.5.19.01 (DIRS 151395-Golder Associates 1998, all). GoldSim is an object-oriented program that is computationally similar to RIP v.5.19.01, which was used for the TSPA–Viability Assessment (DIRS 101779-DOE 1998, Volume 3, p. 2-29). GoldSim is designed such that probabilistic simulations can be conducted and represented graphically.

I.4.4 MODIFICATIONS TO THE TSPA–SITE RECOMMENDATION AND SUPPLEMENTAL SCIENCE AND PERFORMANCE ANALYSIS MODELS

This EIS builds on the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, all) and *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-BSC 2001, all) modeling of the Proposed Action (70,000-MTHM) repository configuration. Because this EIS evaluates the possible consequences of ultimately including the entire commercial spent nuclear fuel, DOE-owned spent nuclear fuel, and high-level radioactive waste inventories, an expanded repository area was also considered.

The change from the TSPA–Site Recommendation waste inventory and repository area to a calculation of the performance of an expanded repository includes addition of the Lower Block, shown on Figure I-3, in the calculations. The TSPA–Site Recommendation and Supplemental Science and Performance Analyses reports relied only on a detailed analysis of just the Primary Block shown on Figure I-3.

The GoldSim numerical code simulates transport of radionuclides from the repository, through the unsaturated zone, and through the saturated zone to the accessible environment. The different process models included in the GoldSim code are fully described and documented in the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, all). The unsaturated zone transport release nodes and saturated zone transport capture areas for the 70,000-MTHM inventory in the TSPA–Site Recommendation and Supplemental Science and Performance Assessment models were modified for Inventory Modules 1 and 2 to include the Lower Block emplacement area (DIRS 157307-BSC 2001, all).

The GoldSim model configuration used for the Supplemental Science and Performance Analyses was modified to conform to the recently published Environmental Protection Agency Final Rule 40 CFR Part 197. The model also assesses the performance of additional radionuclide inventories and performance scenarios. Sections I.4.4.1 through I.4.4.8 describe the modifications to the TSPA–Site Recommendation and Supplemental Science and Performance Analyses models. The model configuration for the calculations in this EIS differs from earlier performance assessment models in the following areas:

- The model used for the calculations in this EIS used biosphere dose conversion factor based on the RMEI defined in 40 CFR 197.21. The models used in the TSPA–Site Recommendation and Supplemental Science and Performance Analyses used different biosphere dose conversion factors based on the average member of the critical group in the then-proposed 10 CFR 63.115.

- The length of the saturated zone simulated in the model configuration for the calculations in this EIS extends from inside the repository footprint to latitude 36 degrees 40 minutes 13.6661 seconds north, above the highest concentration of radionuclides in the plume of contamination. The RMEI is assumed to reside at this location in the accessible environment. The latitude at this location is at the southwestern corner of the Nevada Test Site.

- Groundwater protection was assessed using an annual representative volume of 3.7 million cubic feet (exactly 3,000 acre-feet) per year of groundwater, as specified at 40 CFR Part 197, to calculate the total alpha activity, the total radium concentration, and the whole-body dose. To calculate all other concentrations not included in the groundwater-protection standard, the water usage was assigned in the same probabilistic manner used in the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, Section 3.9.2.4, p. 3-184) and the *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-BSC 2001, Section 13.3.5, pp. 13-41 to 13-44).

- The waste inventories used for the calculations in this EIS are presented in DIRS 154841-BSC (2001, Table 36, p. 38).

- Waste-package corrosion for the calculations in this EIS would be due to general corrosion independent of temperature, as was true for the TSPA–Site Recommendation. The Supplemental Science and Performance Analyses calculations included temperature-dependent waste package corrosion.

- The process-level lower-temperature operating mode thermal-hydrologic results for this EIS were corrected from those presented in the Supplemental Science and Performance Analyses to include radiative heat transfer in the unsaturated zone modeling with the Nonisothermal Unsaturated-Saturated Flow and Transport model.

I.4.4.1 Modifications to FEHM Particle Tracker Input and Output

The unsaturated zone flow-and-transport modeling in the TSPA–Site Recommendation, in the *FY01 Supplemental Science and Performance Analyses*, and in this EIS are conducted with the Finite Element Heat and Mass (FEHM) model. The movement of fluid and radionuclides released from the waste packages was modeled in the unsaturated zone by means of a particle-tracking algorithm in the TSPA–Site Recommendation and Supplemental Science and Performance Analyses process models (DIRS 153246-CRWMS M&O 2000, p. 2-27; DIRS 155950-BSC 2001, Section 11). The particle-tracking files used in the TSPA–Site Recommendation were modified for the increased inventories of Modules 1 and 2 to allow the FEHM unsaturated zone input regions to correspond to the Lower Block area used for the simulations. The interface file in GoldSim was modified for this case by changing the FEHM nodes used for transport from the Primary Block as considered in the TSPA–Site Recommendation and the Supplemental Science and Performance Analyses for the Proposed Action inventory. The calculations presented in this EIS also include the Lower Block of a potential repository that would also be used for input of mass from an expanded repository area. The FEHM nodes were chosen to correspond to the Lower Block repository coordinates because of the changes to the regions from where mass is captured coming out of the FEHM model (DIRS 155393-CRWMS M&O 2000, Attachments II and III). Capture regions at the surface of the saturated zone would accumulate water and mass released from the repository that had been transported through the unsaturated zone. The capture regions for the Primary Block are shown in Figure I-4. These capture regions were modified to ensure all the mass would be captured and to distribute the mass to the saturated zone capture regions, including release from the Lower Block. Figure I-5 shows the capture regions used for Inventory Modules 1 and 2.

The repository nodes were extracted based on the information and representation of the repository configuration described in *EIS Performance-Assessment Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain* (DIRS 155393-CRWMS M&O 2000, Attachment II). The drifts in the Lower Block were first aggregated into larger groups based on similar elevations. Then the boundary coordinates of the larger groups were used to define rectangular regions. The Software Routine *repocoord1.f* (Version 1.0) (DIRS 155393-CRWMS M&O 2000, Attachment II) was used to extract FEHM nodes within the rectangular region. The extracted nodes were then plotted using SigmaPlot (Version 4.01, a commercial graphics software package) and nodes that fell beyond the defined drift region were removed from the repository node list. The use of *repocoord1.f* (Version 1.0) in these EIS calculations is documented in DIRS 155393-CRWMS M&O (2000, Attachment II).

I.4.4.2 Estimation of the Thermal Profiles and Infiltration for the Lower Block

The TSPA–Site Recommendation and *FY01 Supplemental Science and Performance Analyses* models used to assess repository performance utilized thermal-hydrologic modeling to estimate infiltration from land surface to the repository horizon. Infiltration water would be the principal cause of waste-package corrosion and the main agent for waste transport. The TSPA–Site Recommendation and *FY01 Supplemental Science and Performance Analyses* model conceptualizations for the Yucca Mountain Repository would be considered waste forms in discrete areal regions of the repository as source terms for flow and transport from the repository to the saturated zone. The GoldSim conceptualization for the TSPA–Site Recommendation considered the repository block, referred to as the Primary Block, to be comprised of four source regions (Figure I-4). The four regions are covered by the Yucca Mountain multiscale thermohydrologic model and its abstraction, which was used to develop the thermodynamic-environment time histories at different potential waste-package locations distributed throughout the Primary Block (DIRS 139610-CRWMS M&O 2000, Section 6.6, all; DIRS 154594-CRWMS M&O 2001, Section 6.3). These time histories for the higher-temperature operating mode were used in both the TSPA–Site Recommendation and the *FY01 Supplemental Science and Performance Analyses*.

The calculations for Inventory Modules 1 and 2 for this EIS used two additional areas for disposal, using an additional approximately 0.88 square kilometer (218 acres) of the Primary Block that was not used in the design of the Primary Block for the Proposed Action, the higher-temperature operating mode (DIRS 150941-CRWMS M&O 2000, Figure 4-14), and approximately 1.7 square kilometers (408 acres) of the Lower Block, which would be to the east of the Primary Block (Figure I-3). For Inventory Modules 1 and 2, source region 2 was expanded to the east so that its areal extent would include the Lower Block (Figure I-5) (DIRS 155393-CRWMS M&O 2000, Section 5.2.2, p. 11-12).

The following methodology was used to develop thermal histories for waste packages emplaced in the Lower Block. The thermal response from the multiscale thermohydrologic model (DIRS

149862-CRWMS M&O 2000, all) is correlated to the distance from the edge of the repository. Further, seepage into the drift would be a function of the local infiltration flux. Therefore, the location and estimated infiltration flux were used to select analogous Primary Block thermal-hydrologic responses for application to comparable locations in the Lower Block. Thus, the Primary Block thermal-hydrologic data were extended to the 51 Lower Block elements shown on Figure I-6. It should be noted that DOE would pursue a comprehensive characterization of these blocks before it used them for waste emplacement. The modeling work described in this EIS related to these uncharacterized blocks is limited to estimating the environmental impacts under the expanded inventory (Modules 1 and 2) configuration. The detail on extending this method to the 51 nodes is in DIRS 155393-CRWMS M&O (2000, Attachment II, pp. II-2 to II-5), and the estimation of lower-block infiltration seepage rates is in DIRS 155393-CRWMS M&O (2000, Attachment III, pp. III-2 to III-19). The glacial-transition climate infiltration rate for the 51 elements was estimated from the site-scale hydrologic model (DIRS 100103-Bodvarsson, Bandurraga, and Wu 1997, all). For each of the 51 Lower Block elements, the GoldSim code was configured with thermal history data sets from the site multiscale thermohydrologic model (DIRS 139610-CRWMS M&O 2000, Section 6.6, all, and its abstractions; DIRS 154594-CRWMS M&O 2001, Section 6.3) based on similar infiltration and proximity to the edge of the repository as the analogous Primary Block locations. Using these data, the infiltration categories, or bins, for the waste packages associated with the Inventory Modules 1 and 2 cases were established as described in Attachment IV of the calculation document *EIS Performance-Assessment Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain* (DIRS 155393-CRWMS M&O 2000, pp. IV-2 to IV-4). The use of thermal profiles in estimating infiltration to the repository blocks is described in detail in Attachment III of the calculation document *EIS Performance-Assessment Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain* (DIRS 155393-CRWMS M&O 2000, pp. III-2 to III-19). DIRS 157307-BSC (2001, Attachment II) describes the calculation of the fractional Lower Block repository areas corresponding to the infiltration bins for these calculations.

I.4.4.3 Saturated Zone Breakthrough Curves

Transport in the saturated zone beneath the repository would be the main route for groundwater transport of contaminants leached from the repository. The radioactive contaminants would move through the saturated zone to the accessible environment. The accessible environment is defined as any area outside the controlled area (40 CFR 197.12). The Environmental Protection Agency Final Rule (40 CFR 197.12) specifies the following elements of the controlled area:

1. The surface area, identified by passive institutional controls, that encompasses no more than 300 square kilometers (about 74 acres). It must not extend farther:

    a. South than 36 degrees 40 minutes 13.6661 seconds north latitude, in the predominant direction of groundwater flow; and

    b. Than 5 kilometers (3 miles) from the repository footprint in any other direction; and

2. The subsurface underlying the surface area.

The location where the RMEI would reside, where groundwater protection was analyzed, would be the point above the highest concentration of radionuclides in the simulated plume of saturated zone contamination where the plume crossed the southernmost boundary of the controlled area (at a latitude of 36 degrees 40 minutes 13.6661 seconds North) and reached the accessible environment. For this analysis, DOE selected the southern boundary of the controlled area and the location of the RMEI to be at the limit discussed above, which is approximately 18 kilometers (11 miles) from the potential repository, compared to the corresponding distance of approximately 20 kilometers (12 miles) used in the saturated zone transport modeling for TSPA–Site Recommendation and the *FY01 Supplemental Science and*

Performance Analyses, as shown in Figure I-7. To analyze long-term performance with respect to the standard set in the Environmental Protection Agency Final Rule 40 CFR 197.12, additional saturated zone breakthrough curves, which describe the time-related arrivals of radionuclides at the RMEI location, were calculated for all radionuclides used in the calculations in this EIS. The saturated zone breakthrough curves were used in the analyses to simulate radionuclide transport from the water table beneath the proposed repository to the receptor location. Depending on the subsurface layout of a repository, the distance to the RMEI location from any point in the subsurface layout could be more or less than 18 kilometers. For convenience and consistency with other documents, the RMEI location is consistently discussed as being approximately 18 kilometers (11 miles) downgradient from the proposed repository.

To generate the saturated zone breakthrough curves used in the calculations in this EIS, 100 realizations of the saturated zone site-scale flow-and-transport model were performed as described for the saturated zone process model (DIRS 139440-CRWMS M&O 2000, Sections 6.2 and 6.3) to generate saturated zone breakthrough curves at the RMEI location. Other stochastic parameters for the saturated zone simulations use the same values as those used in the saturated zone breakthrough curves for the *FY01 Supplemental Science and Performance Analyses* (DIRS 154659-BSC 2001, Section 3.2.10). The simulated radionuclide breakthrough curves at the RMEI location exhibited shorter transport times than those at 20 kilometers (12 miles), as presented in *Supplemental Sciences and Performance Analyses* (DIRS 155950-BSC 2001, Section 13.2.1.3) on a realization-by-realization basis. In particular, radionuclides that could have significantly greater sorption in the alluvium than in the volcanic units (such as neptunium-237) exhibited shorter transport times to the RMEI location in this analysis relative to the 20-kilometer location used in the TSPA–Site Recommendation, the *Supplemental Science Performance Analyses*, and in the Draft EIS. This result is related to the fact that the RMEI location in this analysis would result in a decrease in the length of transport through the alluvium relative to the transport path to the 20-kilometer location.

The approach used for simulations of groundwater flow and radionuclide transport in the saturated zone used in this EIS is the same as the approach used in the TSPA–Site Recommendation. The saturated zone site-scale flow-and-transport model was used to simulate the unit radionuclide mass breakthrough curves for radionuclides of concern to the Site Recommendation at the RMEI location. In the model configuration for the calculations for this EIS, these saturated zone breakthrough curves are coupled with the other components of the system (mass flux and representative volume or water usage) using the convolution-integral method in the same manner as described and implemented in the GoldSim program for the TSPA–Site Recommendation and the *FY01 Supplemental Science and Performance Analyses* (DIRS 153246-CRWMS M&O 2000, Section 2.2.2; DIRS 155950-BSC 2001, Section 3.2.10). In addition, the simulation of radionuclide decay chains and the transport of decay products in the saturated zone system was performed using a one-dimensional model directly in the GoldSim numerical code.

In the saturated zone model, the capture regions that would accumulate flow and mass at the base of the unsaturated zone become the source regions for the saturated zone model. The four radionuclide source regions in the saturated zone (Figures I-4 and I-5) that were defined for the 70,000-MTHM case of the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, Section 3.8.2.2 and Figure 3.8-14, p. F3-117) were used in the calculations in this EIS. For Inventory Modules 1 and 2, radionuclide mass originating from the Lower Block of the repository is applied to source region number 2 in the saturated zone transport module. The Lower Block of the expanded repository would extend farther to the east than the saturated zone source region number 2 for the TSPA–Site Recommendation base case. However, applying the radionuclide mass from the Lower Block to this source region constitutes a conservative approximation of transport in the saturated zone. Lower permeability rocks of the upper volcanic confining unit exist at the water table in the area immediately to the east of saturated zone source region number 2, which would result in slower initial advective groundwater velocity for radionuclide transport in this area. Preliminary results of radionuclide transport simulations with the saturated zone site-scale flow and transport model confirm that radionuclide transport times in the saturated zone from the area below the Lower Block would be longer than the transport times from saturated zone source region number 2 in the Proposed Action considered in this EIS.

I.4.4.4 Modification to the Waste Package Degradation Model

The WAste Package DEGradation (WAPDEG) model (DIRS 151566-CRWMS M&O 2000, all) was used to calculate drip shield and waste package degradation profiles with time in the GoldSim TSPA model configurations used for TSPA–Site Recommendation, *FY01 Supplemental Science and Performance Analyses*, and this EIS. Several input parameters to the WAPDEG model developed for TSPA–Site Recommendation (DIRS 151566-CRWMS M&O 2000, all) were reevaluated in the *FY01 Supplemental Science and Performance Analyses*, Volume 1 (DIRS 155950-BSC 2001, Section 7). The reevaluation led to the following changes to the TSPA–Site Recommendation WAPDEG model and parameters used in the *FY01 Supplemental Science and Performance Analyses* and the calculations in this EIS. These changes are described in detail in *FY01 Supplemental Science and Performance Analyses*, Volume 1 (DIRS 155950-BSC 2001, Section 7) and are summarized here:

- All surface-breaking weld flaws and all weld flaws embedded in the outer one quarter of the closure weld thickness were considered capable of propagation in the radial direction in the WAPDEG model developed for the TSPA–Site Recommendation (DIRS 151566-CRWMS M&O 2000, Section 5.5, p. 39). In the *FY01 Supplemental Science and Performance Analyses* and in this analysis, the fraction of these weld flaws capable of propagation in the radial direction is given by a ±3 standard deviation truncated lognormal distribution with a mean of 0.01 and bounded between 0.5 (+3 standard deviations) and 0.0002 (-3 standard deviations) (DIRS 155950-BSC 2001, Section 7.3.3.3.4, p. 7-41).

- The stress threshold for the initiation of stress corrosion cracking was given by a uniform distribution between 20 and 30 percent of the Alloy-22 yield strength in the WAPDEG model developed for the TSPA–Site Recommendation (DIRS 151566-CRWMS M&O 2000, Section 4.1.9, p. 29). In the *FY01 Supplemental Science and Performance Analyses* and for this analysis, the stress threshold for the initiation of stress corrosion cracking is given by a uniform distribution between 80 and 90 percent of the Alloy 22 yield strength (DIRS 155950-BSC 2001, Section 7.3.3.3.3, p. 7-39).

- The uncertainty bounds of the residual stress profile in the Alloy-22 waste package outer closure lid weld regions (induction annealed) were set to ±30 percent of the yield strength of Alloy-22 in the WAPDEG Model developed for TSPA–Site Recommendation (DIRS 151566-CRWMS M&O 2000, Section 6.5.1, p. 79). In the *FY01 Supplemental Science and Performance Analyses* and in this analysis, the uncertainty bounds of the residual stress profile in the Alloy-22 waste package outer closure lid weld regions were set to ±21.4 percent of the yield strength (DIRS 155950-BSC 2001, Section 7.3.3.3.1, p. 7-74).

- The uncertainty bounds of the residual stress profile in the Alloy-22 waste package inner closure lid weld regions (laser peened) were set to ±30 percent of the yield strength of Alloy-22 in the WAPDEG model developed for TSPA–Site Recommendation (DIRS 151566-CRWMS M&O 2000, Section 6.5.1, p. 79). In the *FY01 Supplemental Science and Performance Analyses* and in this analysis, the uncertainty bounds of the residual stress profile in the Alloy-22 waste package inner closure lid weld regions were sampled from a cumulative distribution function (DIRS 155950-BSC 2001, Section 7.3.3.3.2, p. 7-37 and Table 7.3.3-2, p. 7T-4).

- The variances of the general corrosion rate distributions for Alloy-22 and titanium Grade 7 were considered to result from contributions of both uncertainty and variability in the WAPDEG model developed for the TSPA–Site Recommendation (DIRS 151566-CRWMS M&O 2000, Section 6.3.1, p. 55). In *FY01 Supplemental Science and Performance Analyses* and in this analysis, the total variance of the general corrosion rate distributions was treated as uncertainty (DIRS 155950-BSC

2001, Section 7.3.5.2, p. 7-54). To ensure conservatism in the analysis, the temperature-dependent Alloy-22 general corrosion model developed for the *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-BSC 2001, Section 7.3.5.3.2, p. 7-56) was not used in this analysis. This is conservative because the non-temperature-dependent model uses a high bounding rate characteristic of high temperature, while the temperature-dependent model would take credit for long periods of lower temperatures and corresponding low corrosion rates. The same Alloy-22 and titanium Grade 7 general corrosion rate distributions used in the WAPDEG model developed for TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000. Section 3.4.1, pp. 3-80 to 3-87) and the *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-BSC 2001, Section 7.3.5, pp. 7-52 to 7-61) were also used in the calculations in this EIS. The calculated means of the general corrosion rate distribution used for the calculations in this EIS are 1.94×10^{-4} millimeter (7.64×10^{-6} inch) per year for titanium Grade 7 and 6.80×10^{-5} millimeter (2.68×10^{-6} inch) per year for Alloy-22. The data used to calculate the means are from complementary distribution functions in *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (DIRS 151566-CRWMS M&O 2000, Section 4, pp. 19 and 20).

I.4.4.5 Early Waste Package Failure

The potential waste package early failure mechanisms were reevaluated in the *FY01 Supplemental Science and Performance Analyses*, particularly improper heat treatment of waste packages (DIRS 155950-BSC 2001, Section 7.3.6, p. 7-62). These results are incorporated in the calculations in this EIS. The probability of having one or more waste packages in the repository improperly heat-treated is provided in Table I-3.

In evaluating the potential consequences of early failures by improper heat treatment for the *FY01 Supplemental Science and Performance Analyses* and this EIS, early waste-package failure would occur on initiation of corrosive processes and would be due to failure of the outer and inner closure lids of the waste package outer barrier and the failure of the closure lid of the stainless-steel structural waste package inner shell. Details of the use of this model in performance assessment analyses are discussed in *FY01 Supplemental Science and Performance Analyses*, Volume 2 (DIRS 154659-BSC 2001, Section 3.2.5.4, p. 3-21). The following elements were employed in that evaluation:

1. Those waste packages affected by early waste-package failure would fail immediately by general corrosion as patches (DIRS 154659-BSC 2001, Section 3.2.5.4, p. 3-21).

2. The area on the waste package affected by improper heat treatment would be equal to the area of closure-weld patches because improper heat treatment would be most likely to occur during the induction annealing of the outer closure lid welds of the waste-package outer barrier.

3. The materials of the entire affected area would be lost on failure of the waste packages because the affected area would be subject to stress-corrosion cracking and highly enhanced localized and general corrosion.

4. The weld region of the inner closure lid of the outer barrier and the closure lid of the stainless-steel structural inner shell would fail at the same time the outer closure-lid weld region failed.

These assumptions are conservative because only the weld region of the outer lid of the outer barrier would be affected by potential improper heat treatment during the stress mitigation heat treatment (induction annealing), and the inner lid of the outer barrier would be unlikely to be affected. In a more realistic scenario, the breached weld patches of the affected waste package would remain with the waste package until the weakened areas were affected by a major mechanical impact or corroded away by general corrosion.

I.4.4.6 Biosphere Dose Conversion Factors for the 40 CFR 197 Reasonably Maximally Exposed Individual

Biosphere dose conversion factors were used to estimate the radiation dose that would be incurred by an individual when a unit activity concentration of a radionuclide reached the accessible environment. The biosphere dose conversion factors for the RMEI were developed using the environmental and agricultural parameters characteristic of the Amargosa Valley region, and the dietary and lifestyle characteristics of the RMEI consistent with those specified in 40 CFR 197.21. The lifestyle characteristics of the RMEI were representative of a rural-residential population. The dietary characteristics of the RMEI were based on a food consumption survey (DIRS 100332-DOE 1997, all) for the population of the town of Amargosa Valley, Nevada. Consistent with the final rule at 40 CFR 197.21, the dietary characteristics of the RMEI were represented by the mean values of locally produced food for Amargosa Valley residents. The dietary and lifestyle attributes of the RMEI are listed in Table I-10. The dietary attributes were developed using the set of recently reevaluated and updated values of consumption rates of locally produced food in *Calculation: Consumption Rates of Locally Produced Food in Nye and Lincoln Counties* (DIRS 156016-BSC 2001, all). This set of consumption rates is different from the set used in the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, Section 3.9) and the *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-BSC 2001, Section 13) analyses. The changes include the update of the contingent average daily intakes of food, adjustments in the grouping of the food categories, and adjustments in the selection of individuals whose consumption rates were used to develop the RMEI.

Table I-10. Average values of the dietary and lifestyle attributes for the RMEI.

Parameter	Mean value of the attribute
Leafy vegetables consumption rate (kilograms[a] per year)	3.9
Other vegetables consumption rate (kilograms per year)	4.8
Fruit consumption rate (kilograms per year)	12.4
Grain consumption rate (kilograms per year)	0.3
Meat consumption rate (kilograms per year)	2.6
Poultry consumption rate (kilograms per year)	0.4
Milk consumption rate (liters[b] per year)	4.8
Eggs consumption rate (kilograms per year)	5.6
Fish consumption rate (kilograms per year)	0.3
Water consumption rate (liters per year)	730
Inadvertent soil ingestion (milligrams[c] per day)	50
Inhalation exposure time (hours)	5,073.5
Soil exposure time (hours)	2,387

a. To convert kilograms to pounds, multiply by 2.2046.
b. To convert liters to gallons, multiply by 0.26417.
c. To convert milligrams to ounces, multiply by 0.000035274.

The biosphere dose conversion factors for the RMEI, characterized by the set of attributes listed in Table I-10, are given in Table I-11.

I.4.4.7 Igneous Activity Scenario

The model and parameter changes from TSPA–Site Recommendation to the model configuration used in the analysis for this EIS for the igneous activity scenario are described in detail in *FY01 Supplemental Science and Performance Analyses*, Volume 1 (DIRS 155950-BSC 2001, Sections 13 and 14) and are summarized here.

Several input parameters to the TSPA models used to calculate consequences of igneous disruption changed after the TSPA–Site Recommendation and have been included in this analysis (DIRS 155950-

Table I-11. Biosphere dose conversion factors for the RMEI for the groundwater release and the volcanic release exposure scenarios.

Radionuclide	Groundwater release[a] (rem per picocurie per liter[b])	Volcanic release[a] (rem per picocurie per square meter[c])
Carbon-14	0.000029	NA[d]
Selenium-79	0.000012	3.8×10^{-11}
Strontium-90	0.0002	4.2×10^{-9}
Technetium-99	0.0000028	NA
Iodine-129	0.00025	NA
Cesium-137	0.00034	1.2×10^{-9}
Lead-210	0.0051	1.4×10^{-8}
Radium-226	0.005	4.2×10^{-9}
Actinium-227	0.013	1.9×10^{-6}
Thorium-229	0.0061	6.0×10^{-7}
Thorium-230	0.0012	9.1×10^{-8}
Protactinium-231	0.016	3.8×10^{-7}
Uranium-232	0.0018	1.9×10^{-7}
Uranium-233	0.00028	3.8×10^{-8}
Uranium-234	0.00027	3.8×10^{-8}
Uranium-236	0.00026	NA
Uranium-238	0.00026	NA
Neptunium-237	0.0045	1.9×10^{-7}
Plutonium -238	0.0029	1.1×10^{-7}
Plutonium-239	0.0035	1.3×10^{-7}
Plutonium -240	0.0035	1.3×10^{-7}
Plutonium-242	0.0032	1.2×10^{-7}
Americium-241	0.0035	1.3×10^{-7}
Americium-243	0.004	1.3×10^{-7}

a. Biosphere Dose Conversion Factors for the transition phase, 1 centimeter (0.4 inch) layer of ash and annual average mass loading
b. To convert liters to gallons, multiply by 0.26417.
c. To convert from square meters to square feet, multiply by 10.764.
d. NA = not applicable.

BSC 2001, Section 14.3.3.7). Consistent with new information regarding the probability of an eruption at the location of the proposed repository given an igneous intrusive event (DIRS 155950-BSC 2001, Section 14.3, all), the conditional probability of an eruption at the proposed repository was revised from 0.36 (DIRS 153246-CRWMS M&O 2000, Table 3.10-4, p. 198) to 0.77 (DIRS 155950-BSC 2001, Section 14.3.3.1, p. 14-13). According to *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (DIRS 151551-CRWMS M&O 2000, Section 6.5.3.2, and Table 12a, p. 130), the approach for the calculation of the conditional number of eruptive centers occurring within the repository footprint was modified by: 1) using empirical distributions for the average spacing between eruptive centers rather than the expected values for these distributions, and 2) incorporating uncertainty in the effect of the repository opening on the conditional probability of the occurrence of an eruptive center within the repository footprint. This modified approach resulted in the new conditional probability of 0.77 for one eruptive center to occur involving the Primary Block of the higher-temperature repository operating mode footprint during or coincident with an igneous activity event. This conditional probability has also been assumed for the lower-temperature operating mode analyses in Section I.5.

Changes also were made in the probability distribution for an intrusive event, consistent with revisions in the repository footprint (changes related to the higher-temperature operating mode) because inputs were compiled for TSPA–Site Recommendation. Revised distributions were provided for the number of waste packages affected by igneous intrusion and volcanic eruption events, consistent with the revised event probability information for the Primary Block of the higher-temperature operating mode. This adjusted event probability has also been assumed for the lower-temperature operating mode analyses in Section I.5. Changes have been made in the input data used to determine the wind speed during an eruption (DIRS 155950-BSC 2001, Section 3.3.1.2.1). Additional changes in inputs to the TSPA–Site Recommendation igneous consequence model are listed in *FY01 Supplemental Science and Performance Analyses*, Volume 1 (DIRS 155950-BSC 2001, Section 14.3.3.7, p. 14-24, and Tables 14.3.3.7-1 and 14.3.3.7-2, p. 14T-5 to 14T-6). Other model inputs and assumptions, including the assumption that wind direction would be fixed toward the location of the exposed individual at all times, were the same as those used in the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, Section 3.10).

I.4.4.8 Human Intrusion Scenario

The human intrusion scenario for the calculations in this EIS was developed from that in the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, Section 4.4). The model changes implemented for the human intrusion calculations in this EIS are described in this section.

Errata in the TSPA–Site Recommendation human intrusion model associated with "boosting" the inventory of certain radionuclides to account for first-generation decay product transport through the three-dimensional saturated zone model (DIRS 148384-CRWMS M&O 2000, Section 6.3.4.1, p. 233) were corrected.

In the TSPA–Site Recommendation human intrusion submodel (DIRS 148384-CRWMS M&O 2000, Section 6.3.9.3, p. 513), for the purpose of determining thermal-hydrologic conditions, in-package chemistry, and in-drift chemistry, the failed waste package was placed in a specified dripping environment for a given infiltration condition. For the calculations in this EIS, the failed waste package for each realization of the human intrusion scenario was randomly placed in one of several dripping environments depending on the infiltration condition.

Colloidal-facilitated transport of americium, plutonium, thorium, and protactinium in an exploratory borehole through the unsaturated zone has been included in the human intrusion scenario in this EIS. The decay products of irreversibly sorbed americium-241 and neptunium-237 were included as an irreversibly sorbed colloidal species. Colloidal-facilitated transport was implemented by adjusting the sorption coefficients of the aforementioned nuclides according to the relationship (DIRS 139440-CRWMS M&O 2000, p. 26):

$$K_d^{adj} = \frac{K_d^{orig}}{1 + K_c}$$

where

K_d^{orig} = sorption coefficient without colloidal-facilitated transport

K_d^{adj} = sorption coefficient with colloidal-facilitated transport

K_c = colloid partition coefficient

The human intrusion scenario in this EIS was simulated for a 1-million-year duration (as opposed to the 100,000-year duration in the TSPA–Site Recommendation). To be consistent with the *FY01 Supplemental Science and Performance Analyses* 1-million-year calculations, two additional radionuclides, radon-228 and thorium-232, were included in the inventory (DIRS 155950-BSC 2001, Section 13.2.1.10, pp. 13-9 and 13-10). The 30,000-year human intrusion scenario is the same scenario analyzed in the *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-BSC 2001, Volume 1, Appendix A). The information in that appendix addresses the issue of when a human intrusion could occur based upon the earliest time that current technology and practices could lead to waste package penetration without the driller noticing waste package penetration. The earliest time would be that time (approximately 30,000 years) when the waste package had corroded sufficiently that a drill bit could penetrate it.

The assessment of the human intrusion scenario did not combine the results of this scenario with the results of the disruptive igneous activity scenario. However, combined results can be approximated by adding the results of the human intrusion calculations to the results of the disruptive igneous event scenario. Based on the results in Section I.5, the highest mean annual individual dose that would result from a human intrusion would be less than one-tenth of the radiological dose from a disruptive igneous event.

I.4.5 EXTENSION OF GROUNDWATER IMPACTS TO OTHER DISTANCES

The TSPA model described in Section I.2 was used to model the environmental impacts to groundwater for the long-term postclosure period. The TSPA model was originally developed to support the Yucca Mountain site suitability evaluation and possible subsequent licensing compliance analyses for the repository if the site was recommended. The model is, therefore, focused on the compliance requirements set forth in applicable regulations such as the Environmental Protection Agency standard, 40 CFR Part 197. This standard is concerned with a single compliance point, the RMEI location. The long-term impacts to groundwater predicted by the TSPA model would be restricted to that single location. Supporting models, such as the site-scale flow and transport model, were developed to support the TSPA calculation and do not extend much beyond the RMEI location. Furthermore, the TSPA made a conservative assumption that all radionuclide mass in groundwater would be captured in the water usage at the RMEI location. This is a reasonable approach for the compliance calculations because it tends to bias the concentration of materials to a higher value, without trying to account for complicated plume-capture considerations, and also because the volume of the plume passing this point in 1 year would be on the order of the upper bound of water usage. However, this assumption in the model does not allow it to account for the spreading of the plume at greater distances considered in this EIS.

As part of a comprehensive presentation of impacts, this EIS is charged with providing groundwater impacts for two other important downgradient locations. These are 30 kilometers (18 miles), where most of the current population in the groundwater path is located, and 60 kilometers (37 miles), where the aquifer discharges to the surface (also known as Franklin Lake Playa). The selection of these locations is discussed in Section I.4.5.1.

To provide insight about impacts at these other distances, a method of scaling was developed. This was necessary because the TSPA model is limited to the RMEI location, as described above. This section describes the approach to the scaling and the results obtained. The scaling approach is discussed in Section I.4.5.2 and the scaling factors in Section I.4.5.3.

I.4.5.1 Locations for Assessing Postclosure Impacts to Human Health

The Environmental Protection Agency public health and environmental radiation protection standards for Yucca Mountain (40 CFR Part 197) require DOE to estimate the potential radiation doses to the public from the disposal of spent nuclear fuel and high-level radioactive waste, based on the concept of the RMEI. This involves estimating the dose to a person assumed to be among those at greatest risk for 10,000 years after repository closure, given certain conservative exposure parameters and parameter value ranges. The Environmental Protection Agency selected a theoretical individual representative of a future population group or community, termed *rural-residential*, as the basis of an individual exposure scenario. This rural-residential RMEI would be exposed through the same general pathways as a subsistence farmer; however, the RMEI would not be a full-time farmer but rather would consume some locally grown food (self-grown or from local sources) as part of the exposure scenario. The Environmental Protection Agency also established a maximum 300-square-kilometer (74,000-acre)-controlled area, and established a RMEI location that equates to approximately 18 kilometers (11 miles) south of the repository (the predominant direction of groundwater flow), for demonstrating compliance with the long-term performance standards. The Environmental Protection Agency standard defines the postclosure accessible environment as being any point outside the controlled area.

For purposes of estimating potential environmental impacts in this EIS, DOE considered the impacts to the RMEI approximately 18 kilometers (11 miles) downgradient from the repository, as well as at other reasonable locations. In determining those locations, DOE considered locations where it would be reasonable from a technical and economic standpoint to locate a rural-residential individual. Although there exists a large number of locations at which analyses could be performed, DOE has determined that the most reasonable analyses to perform are for a rural-residential individual approximately 18, 30, and 60 kilometers (11, 19, and 37 miles) downgradient from the proposed repository, because these locations are based on realistic exposure conditions that would provide the basis for a meaningful comparison of potential human health impacts.

The Environmental Protection Agency, in reaching its conclusion on the location of the southernmost extent of the controlled area, considered current and projected uses of the land in the vicinity of the area formerly known as Lathrop Wells [now known as Amargosa Valley, approximately 20 kilometers (12 miles) downgradient from the repository]. The Agency noted there are currently eight residents and fewer than 10 businesses near this location whose source of water is the aquifer that flows beneath Yucca Mountain. This is the location where private property is nearest the proposed repository, and where some soils are suitable for agricultural purposes [the nearest farm is somewhat farther south, about 23 kilometers (14 miles) downgradient from the repository]. The Agency used near-term projections of land development between the current population at Amargosa Valley north to the Nevada Test Site. Near-term plans for the area between Amargosa Valley and the Test Site boundary include a science museum and industrial activities. Therefore, the boundary of the Test Site was used as the southernmost extent of the controlled area in 40 CFR 197.12. For this EIS, DOE adopted the southernmost extent of the controlled area as the RMEI location. This location is about 18 kilometers (11 miles) downgradient from the proposed repository.

DOE also has identified other reasonable locations for a hypothetical rural-residential individual approximately 30 and 60 kilometers (19 and 37 miles) downgradient from the repository. The closest population center is 30 kilometers (19 miles) downgradient in Amargosa Valley. At this location, the depth to groundwater suitable for human consumption and other uses (for example, agricultural) ranges from about 9 to 40 meters (30 to 130 feet) deep (less than that at the location formerly known as Lathrop Wells), and wells supply water to individual households. Franklin Lake Playa is about 60 kilometers (37 miles) downgradient from the proposed repository and is the location where the aquifer could emerge as surface water.

In conclusion, these three locations where a rural-residential individual could be reasonably located [about 18, 30, and 60 kilometers (11, 19, and 37 miles) downgradient] represent realistic locations where water for human consumption and other uses can occur using commonly available techniques without undue costs to withdraw and distribute water. These locations also reflect current populations and lifestyles in areas where dissolved radionuclides in the groundwater could affect future populations.

In the Draft EIS, DOE analyzed a Maximally Exposed Individual at a location 5 kilometers (3 miles) from the repository. The Maximally Exposed Individual was defined as a hypothetical person exposed to radiation in such a way—by a combination of factors including location, lifestyle, dietary habits, and so on—that the individual would be the most highly exposed member of the public. The Maximally Exposed Individual in the Draft EIS was a hypothetical member of a group of adults that would live in the Amargosa Valley with a characteristic range of lifestyle, food consumption, and groundwater usage patterns. This individual would grow half of the foods that the individual would consume on the property, irrigate crops and water livestock using groundwater, and use groundwater as a drinking water source and to bathe and wash clothes. The lifestyle and related exposure characteristics of the Maximally Exposed Individual are similar to those of the Environmental Protection Agency's rural-residential RMEI.

DOE noted in the Draft EIS that there are no permanent residents at a location 5 kilometers (3 miles) downgradient from the repository. The water table lies more than 360 meters (1,200 feet) deep in hard, volcanic rock. Although it might be possible, DOE would not expect permanent residents at that location in the future because of a lack of economically accessible groundwater. Human habitation has occurred in the vicinity of the repository where only the groundwater is easily accessible. Furthermore, the lands in this area are under the control of the Federal Government and within the controlled area defined in 40 CFR Part 197 – and thus are not part of the postclosure accessible environment.

In spite of these factors, DOE analyzed a Maximally Exposed Individual at a location 5 kilometers (3 miles) downgradient of the repository in the Draft EIS. At the time of the Draft EIS, Environmental Protection Agency had not published its draft or final radiation protection standards for Yucca Mountain, but DOE believed that a 5-kilometer compliance location could be established by the Environmental Protection Agency, given a similar compliance location in its generally applicable standards for the disposal of spent nuclear fuel, high-level radioactive waste and transuranic waste (40 CFR 191).

However, the Environmental Protection Agency has since published its final Yucca Mountain-specific public health and environmental radiation protection standards, and has concluded:

> "…it improbable that the rural-residential RMEI [reasonably maximally exposed individual] would occupy locations significantly north of U.S. Route 95 [location formerly known as Lathrop Wells], because the rough terrain and increasing depth to ground water nearer Yucca Mountain would likely discourage settlement by individuals because access to water is more difficult than it would be a few kilometers farther south."

The Environmental Protection Agency considered whether or not the inherent nature of the soils and the topography were conducive to or would constrain further development of the area near Yucca Mountain. The Agency concluded that:

> "…agricultural activity would be limited around Yucca Mountain as a result of adverse conditions, such as steep slopes, rocky terrain, and shallow soils…"

The Environmental Protection Agency also considered the potential dose to a RMEI at locations closer than approximately 18 kilometers (11 miles), and concluded that a rural-residential individual would receive a lower dose than those at 18 kilometers. The Agency stated that:

> "If individuals lived near the repository, they would be unlikely to withdraw water from the significantly greater depth for other than domestic use, and in the much larger quantities needed for gardening or farming activities because of the significant cost of finding and withdrawing the ground water. It is possible, therefore, for an individual located closer to the repository to incur exposures from contaminated drinking water, but not from ingestion of contaminated food. Based upon our analyses…we believe that use of contaminated ground water…would be the most likely pathway for most of the dose from the most soluble, more mobile radionuclides…The percentage of the dose that results from irrigation would depend upon assumptions about the fraction of all food consumed by the RMEI from gardening or other crops grown using contaminated water, which should reflect the

> lifestyle of current residents of the Town of Amargosa Valley. Therefore, the exposure of an RMEI located approximately 18 km south of the repository…actually would be more conservative than an RMEI located much closer to the repository…"

The Agency also addressed the economic feasibility of well drilling and pumping costs and concluded that:

> "…the capital costs of private wells for domestic use become prohibitive at depths between 300 and 600 feet. For communal domestic use and irrigation use, the capital costs do not become prohibitive even at depths of 1,200 feet…However, because of the very large volumes of water needed for irrigating field crops, particularly in the climate of Amargosa Valley, pumping costs are very significant for such agricultural applications. Combining the pumping cost estimates…with the capital cost estimates…the marginal value of water for irrigation is exceeded at depths to water greater than 300 feet. In fact, since these estimates do not consider the distribution cost for the irrigation system or any maintenance costs…it is not surprising to see that commercial agricultural activities in Amargosa Valley have been restricted thus far to areas where the depth to water is generally less than about 200 feet."

Based on the above considerations, DOE did not reevaluate the impacts at 5 kilometers (3 miles). This EIS contains evaluations of impacts at the RMEI location, at 30 kilometers (19 miles) downgradient from the repository (population center), and at the groundwater surface discharge point 60 kilometers (37 miles) downgradient from the repository.

I.4.5.2 Scaling Approach

This section summarizes the approach detailed in DIRS 157520-Williams (2001, Enclosure 3).

As the plume traveled over a given distance in the saturated zone, the concentration of radionuclides in the plume could be attenuated by several effects: dispersion, decay, filtration of solids by the aquifer medium, irreversible sorption of radionuclides by the aquifer medium, and other minor phenomena. The dispersion effects would be due to the combination of molecular diffusion and hydrodynamic mixing, that would tend to cause the contaminants to spread out along and transverse to the path of flow. The dispersion effect would reduce the peak concentration of the plume and increase the volume of the plume. The decay effect would be due to the later arrival of the plume centerline at a farther distance, allowing time for nuclear decay. The travel time would depend on the flow rate of the water and the retardation of contaminants that were sorbed reversibly by the aquifer solid media. The overall reduction by decay would be governed by the radionuclide travel time and the rate of decay of a particular radionuclide. The effects of colloid filtration, irreversible sorption, and other minor phenomena are expected to be small and are normally neglected. The principal radionuclides that would contribute to dose and most significantly affect groundwater quality have very long half-lives (and therefore very slow rates of decay), so the reduction of concentration by decay would be fairly small. The major contributor to the reduction of concentration in the contaminant plume, then, would be the dispersion effect. Therefore, the scaling approach was developed from only the dispersion effect. This produced a conservative result because the decay effect will cause some small additional reduction in concentration.

All of the major attenuating effects listed above were applied in the TSPA model for the calculation of the dose and water quality at the compliance point. However, because most of the path from the proposed repository to the compliance point is in the volcanic aquifer, there is only a small amount of dispersion. The volcanic aquifer is comprised mostly of fractured rock, so flow occurs in small isolated channels and mixing is minimal. This is why the plume is still small at the compliance point and full capture is a reasonable assumption. In the alluvial aquifer that extends from the RMEI location down to the discharge point, the aquifer medium is a finely divided, granular material where flow is slow and considerably more mixing can occur.

An analytical solution to the three-dimensional advection-dispersion problem was used to estimate dispersion effects from the RMEI location to the discharge point (DIRS 157520-Williams 2001, Enclosure 3, all). In these calculations, the groundwater flow velocity in the alluvium was assumed to be horizontal with a constant value of 18 meters (59 feet) per year, corresponding to a specific discharge rate of 2.7 meters (9 feet) per year and an effective porosity of 15 percent throughout the flow domain. These values were derived from the saturated zone site-scale model documented in DIRS 155950-BSC (2001, Section 12). Calculations were done under steady-state conditions, that is, for a source that has been discharging for a long time. The source was assumed to have constant concentration, be within a rectangular shape in the vertical plane, and centered at the repository location. Two source sizes were considered: a small source, 10 meters by 10 meters (33 feet by 33 feet), corresponding to an early failure scenario (localized failing waste package), and a large source, 3,000 meters (9,840 feet) horizontal by 10 meters (32.8 feet) vertical, corresponding to a long-term scenario in which all waste packages would fail.

The calculations were carried out for a range of dispersivities and for two assumed mass captures: 90 percent and 99 percent. The mass capture is a function of the amount of influence a well or field of wells would have in pulling mass from the plume. The results discussed here are restricted to the more conservative 99-percent capture assumption. Two important parameters were considered: the cross-section (perpendicular to flow) of the plume and the relative peak concentration at the center of the plume. As the plume traveled in the groundwater it would spread, so the cross-section would increase (thus reducing the average concentration) and the peak concentration would decrease. A reasonable approximation of distance effect can then be found by using either of these values. The two values will produce a slightly different result. Scaling factors using both approaches are discussed in the next section.

I.4.5.3 Scaling Factors for Dose or Water Quality Concentrations at Longer Distances

Table I-12 lists the resulting scaling factors from the dispersion studies (DIRS 157520-Williams 2001, Enclosure 3, Table 2a). The values are for the assumption of 99-percent capture, the larger realistic dispersion factor set, and two source sizes. The large source size would be applied for nominal scenario peak dose and the small source for localized sources such as the early failures (prior to 10,000 years) due to package defects or igneous intrusion releases, or for doses from the human intrusion scenario. Two sets of scaling factors are listed for each source size: one based on peak concentration and one based on plume cross-section. To obtain a value of dose or groundwater quality concentration at 30 or 60 kilometers (18 or 37 miles), multiply the 18-kilometer (11-mile) value by the appropriate scaling factor. The scaled results reported in Chapter 5, Section 5.4.1, use the plume cross-section factors. This is considered the best choice because the effect of water usage by the communities would be to cause significant mixing, and the more characteristic parameter would be the plume average concentration.

I.5 Waterborne Radioactive Material Impacts

The simulations in support of this analysis estimated the annual individual dose for the Proposed Action, Module 1, and Module 2 inventories. For the purposes of this EIS, DOE determined that the southern boundary of the controlled area would be at the southernmost point from the repository specified in 40 CFR Part 197 (36 degrees, 40 minutes, 13.6661 seconds north latitude). The RMEI location was then defined to be the point where the predominate groundwater flow crosses the boundary. Groundwater modeling indicated this point to be approximately 18 kilometers (11 miles) downgradient from the potential repository. This EIS refers to this location as the “RMEI location.” It corresponds to where the RMEI, a resident in an average farming community, would consume and use groundwater withdrawn from wells. In accordance with 40 CFR 197.35, the annual individual dose was calculated for the period of geologic stability (1 million years). These calculations include simulations for both the 10,000- and 1 million-year performance periods specified in 40 CFR 197.20 and 197.35.